



# Characterizing Uncertainty in Reservoir Inflow Forecasts

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# Approaches



- Statistical (regression based)
  - Traditionally applied to volumetric water management forecasts.
- Error Propagation
  - Applicable to headwater basins for near-term forecasts.
- Ensemble Techniques
  - Applicable across all time domains and locations within river systems.



# Error Propagation

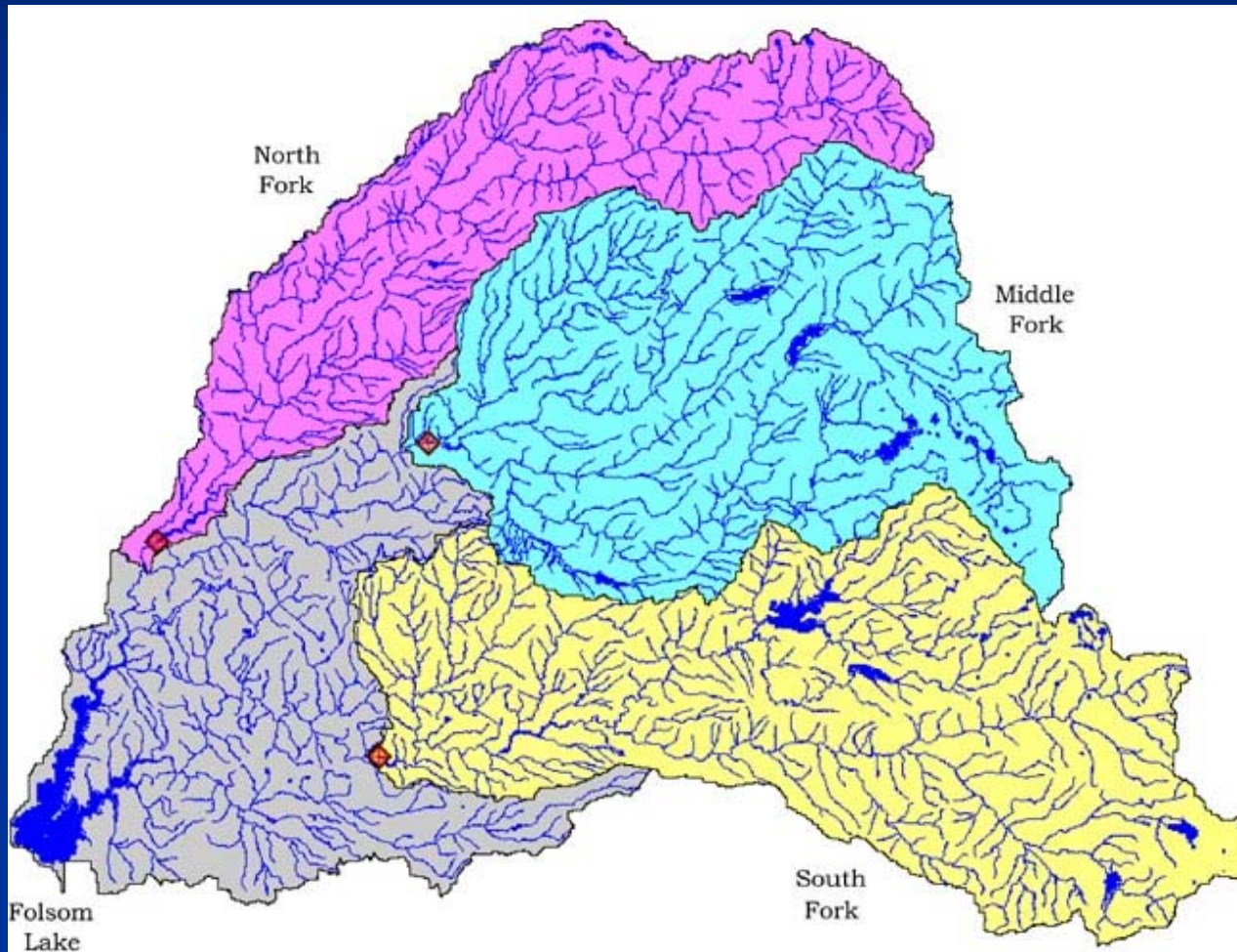


- Reconfiguration of model into “state-space”.
- Uncertainty is propagated through the model states as a natural consequence of operations.
- Requires the estimation of uncertainties associated with the model itself and all of the inputs.



# Folsom Reservoir Inflow

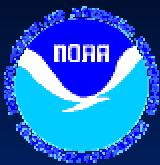
Applied and operated on the American River since 1998.



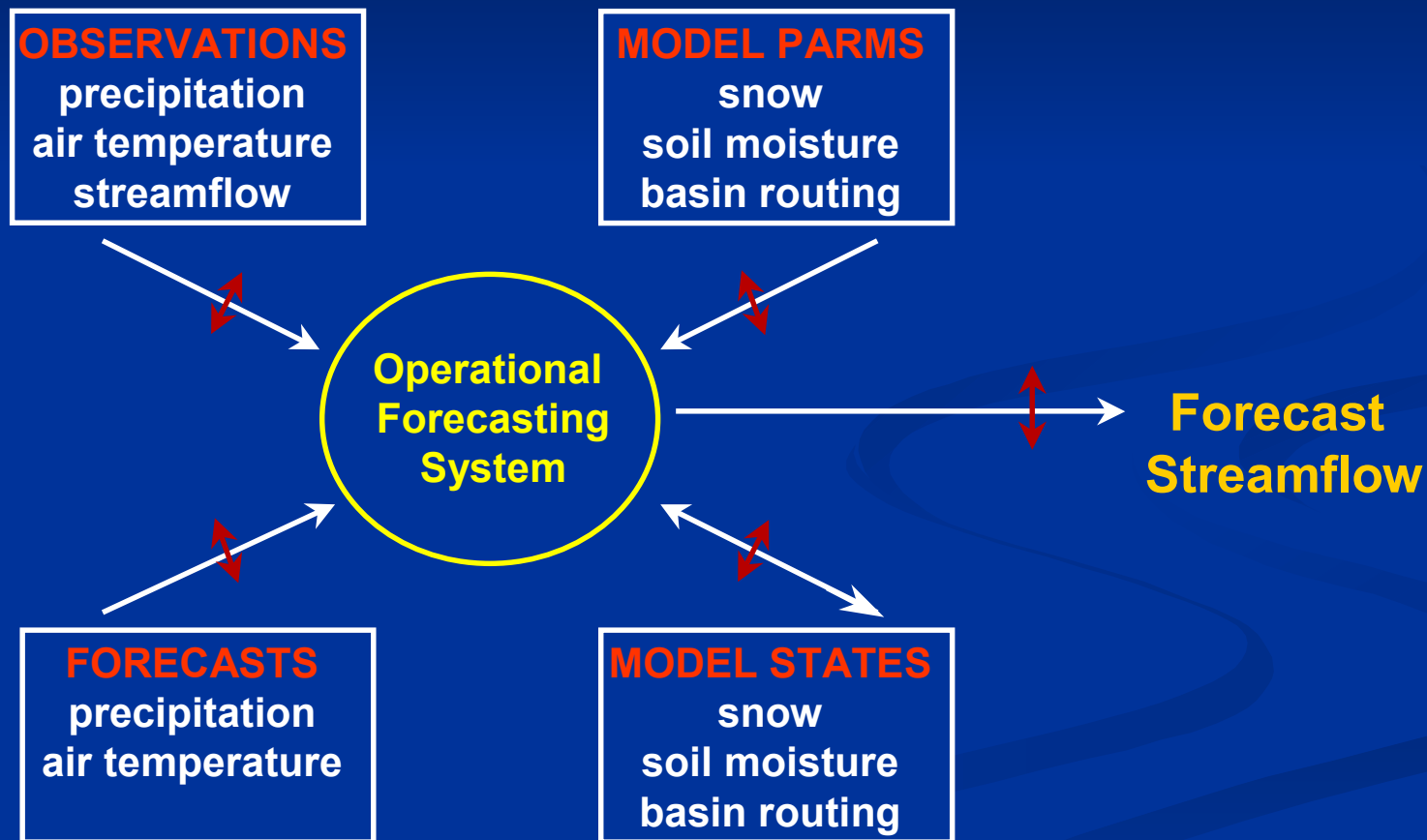


# Operational Folsom Reservoir Inflow Forecasts

- 5 day inflows (6 hour intervals).
- Variance of instantaneous 6 hour inflows.
- Variance of 6 hour volumes.
- Automatically generated and made available to USBR/CVO.
  - minimum 2x/day winter.



# Sources of Uncertainty





# Model Configuration

Air Temperature  $\longrightarrow$  Rain-Snow Operation  
observed/forecast

Precipitation  $\longrightarrow$  Snow Model  
observed/forecast

Soil Moisture Accounting Model

Unit Hydrograph Operation

$\longrightarrow$  Adjustment Technique

SS-SAC

Streamflow  
observed

Routing Operation

Hydrologist  $\longrightarrow$  Forecast Guidance



# Benefits of SS-SAC



- Model States Updated.
  - more accurate model states.
  - more accurate simulation and forecasts.
- Forecast Uncertainty estimated.





# Risks of SS-SAC



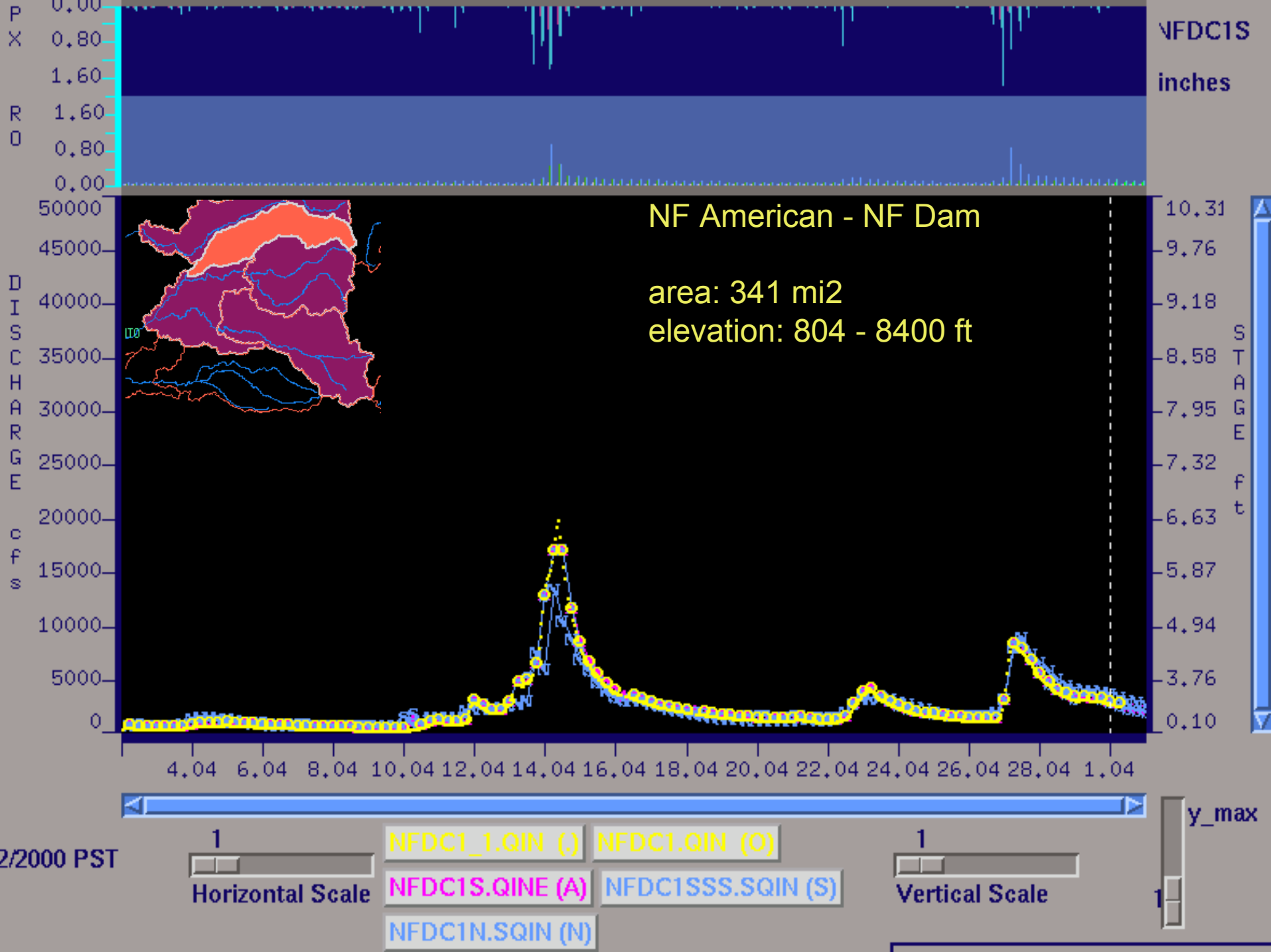
- Susceptible to inaccurate streamflow measurements.
- Magnitude of contributing uncertainties must be reasonably accurate.
- Non-obvious (black box) process.

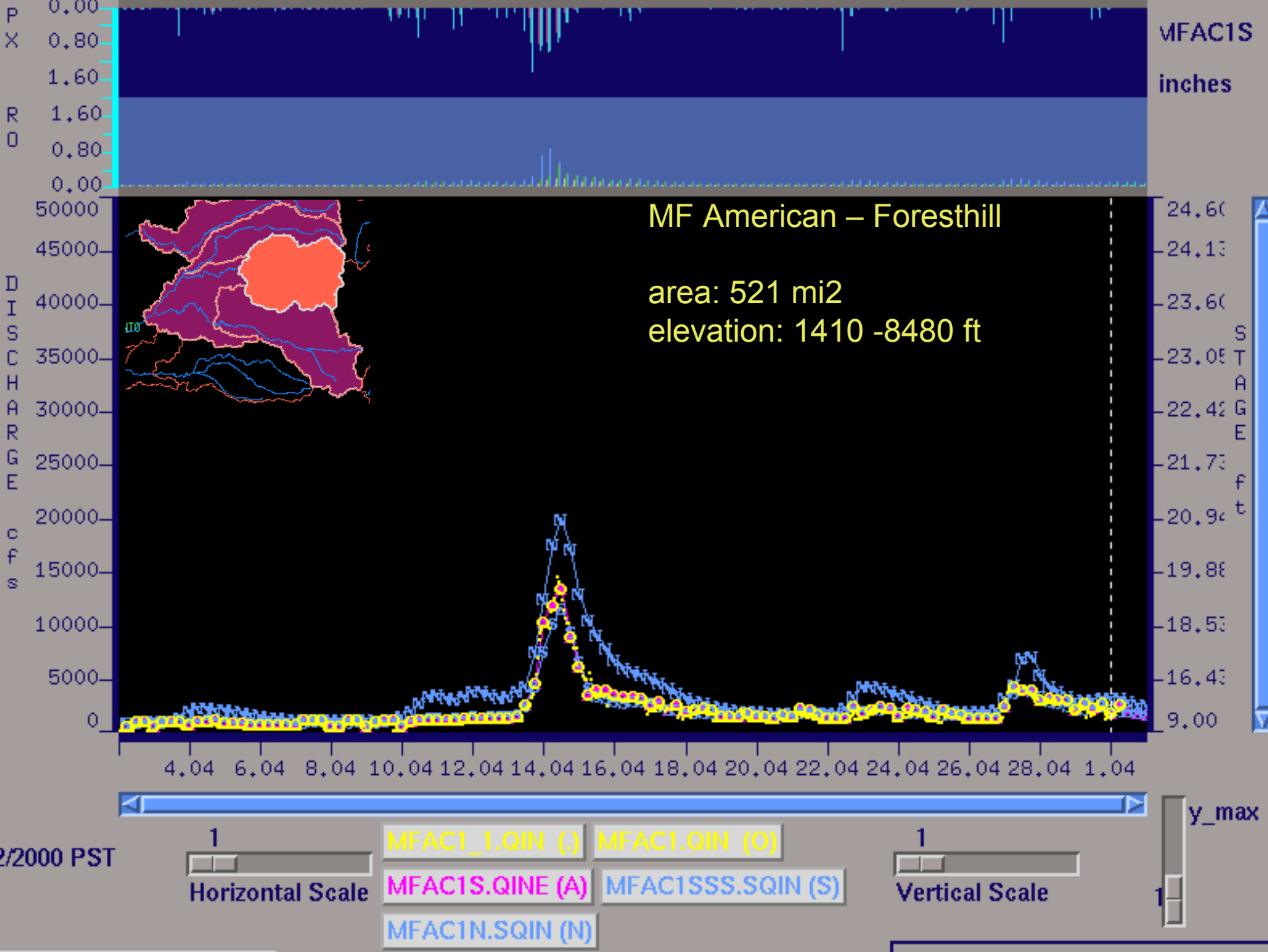


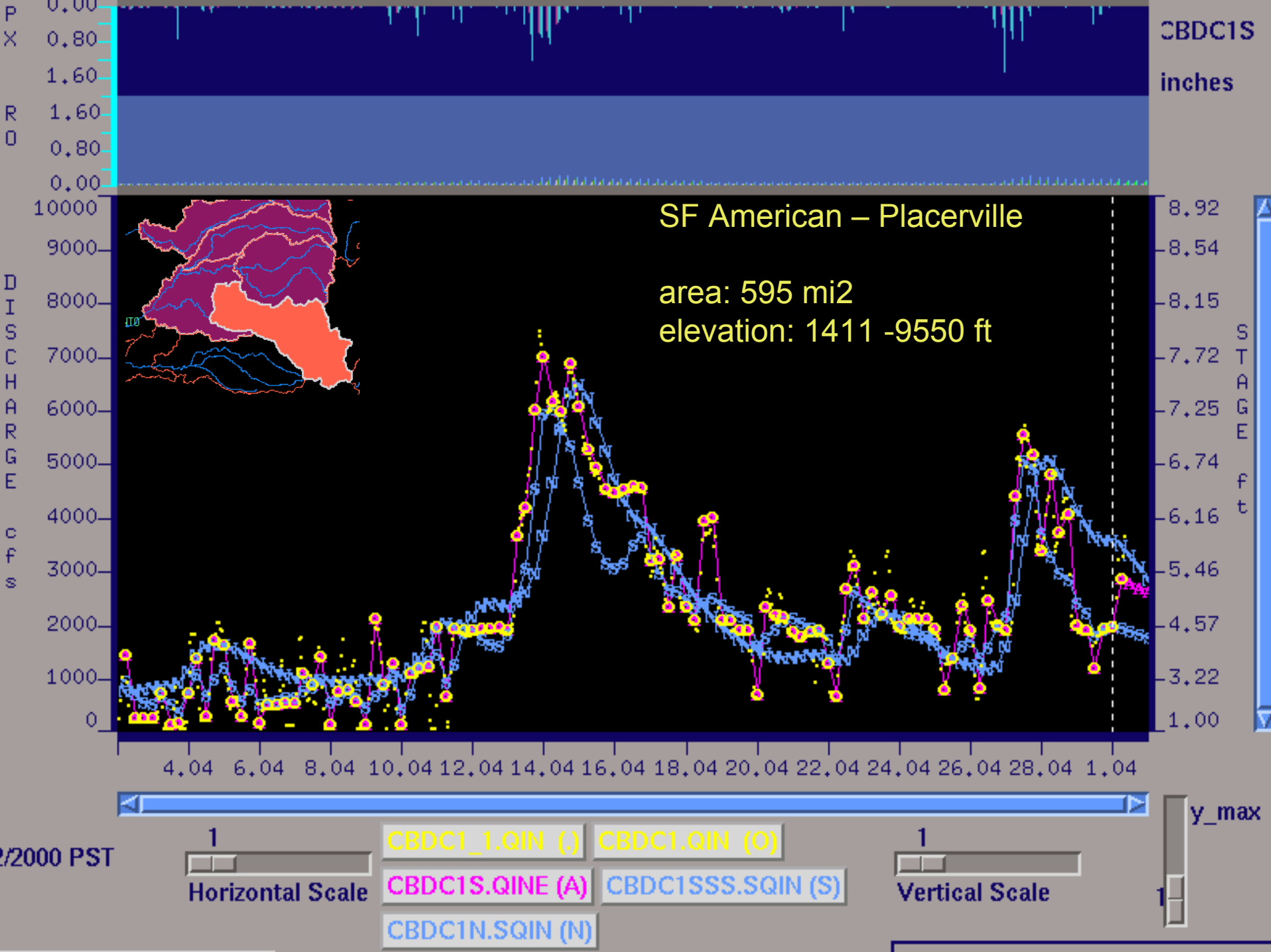
# Limitations of SS-SAC

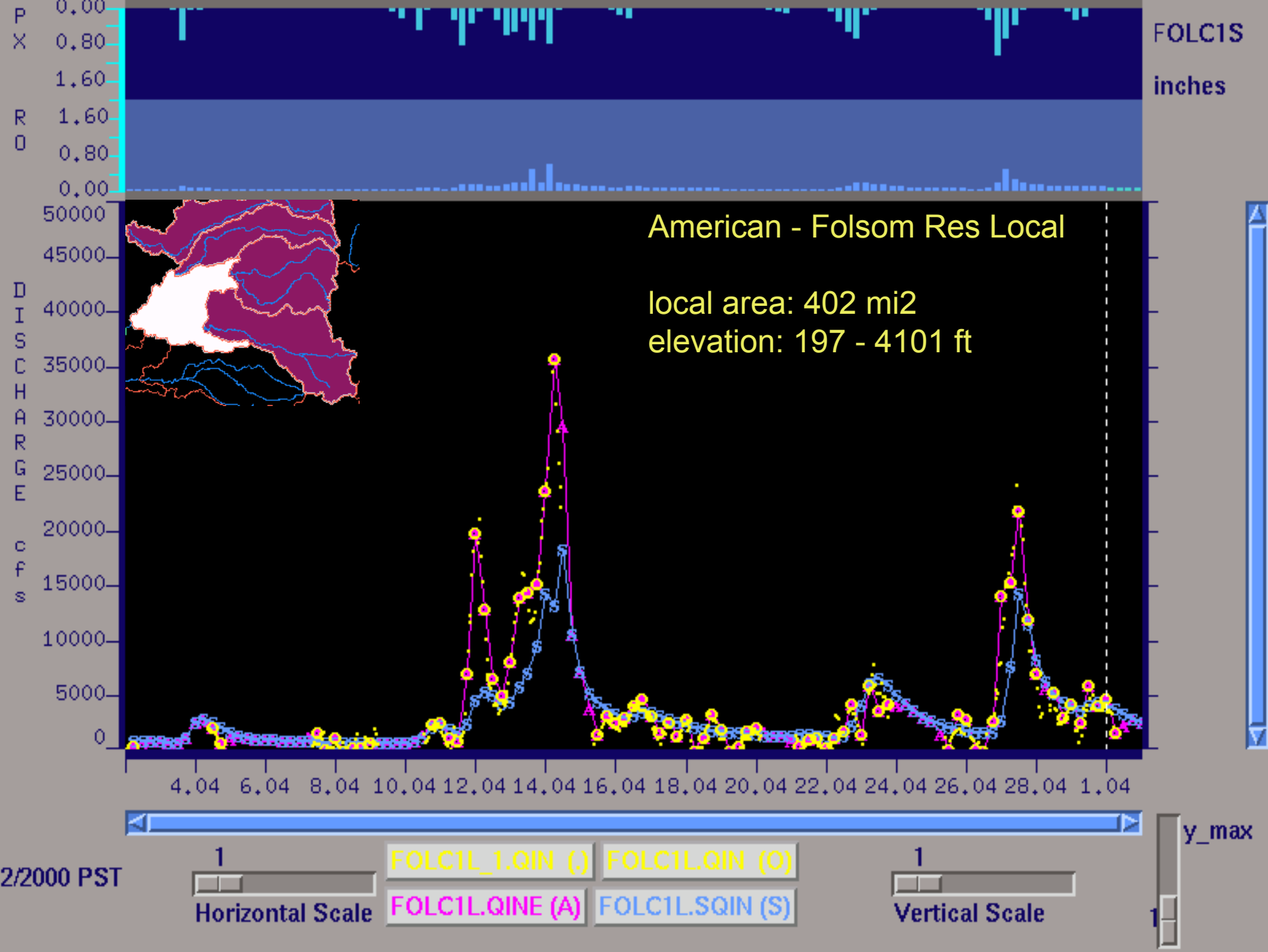


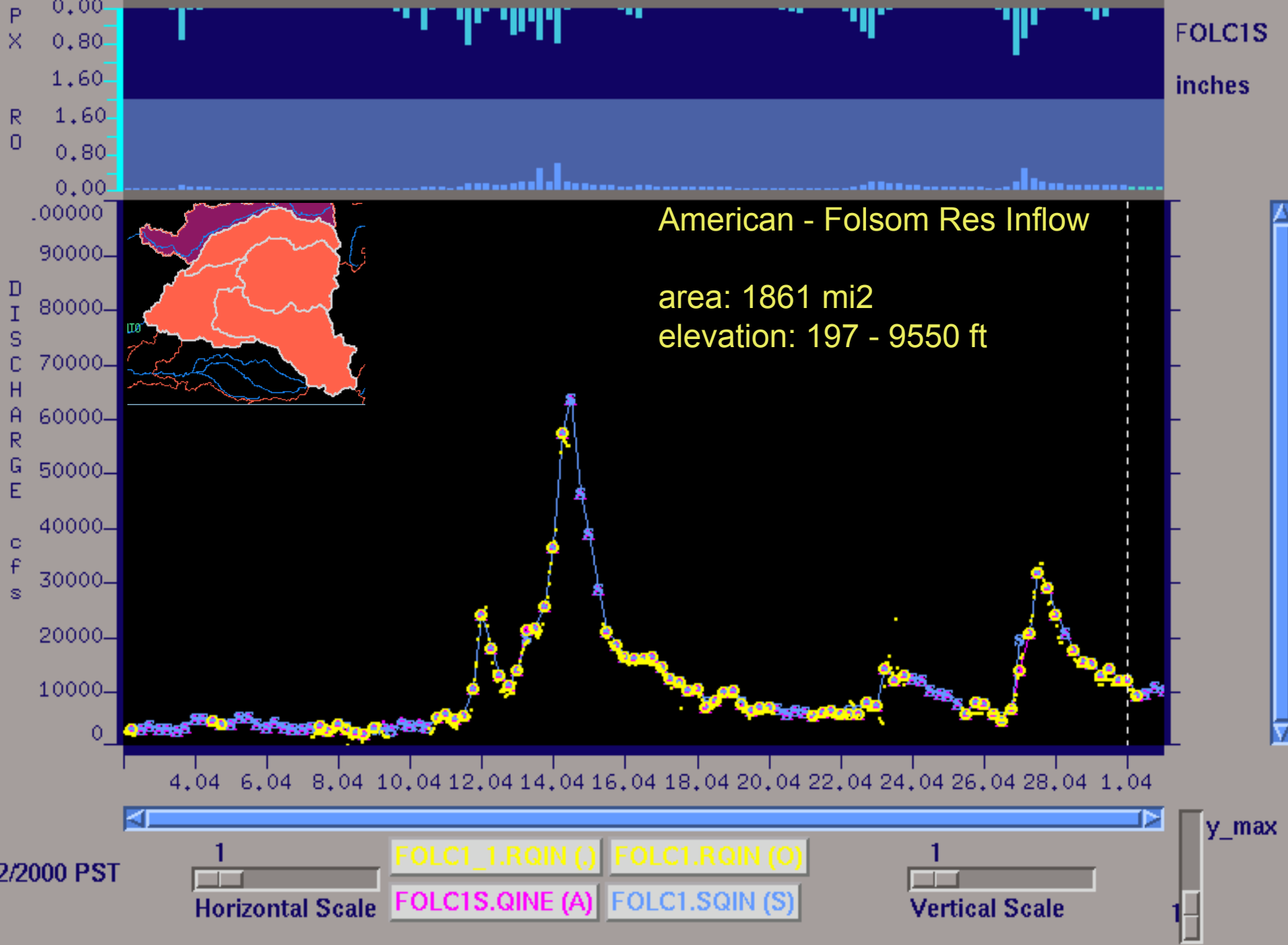
- Uncertainty in snow model (and states) not integrated into system.
- Difficult to apply to non-headwater locations.
  - Techniques for propagating uncertainty downstream through routing reaches and reservoirs have not been developed.
- Customers not well prepared to deal with forecast variances.













# Ensemble Forecasting

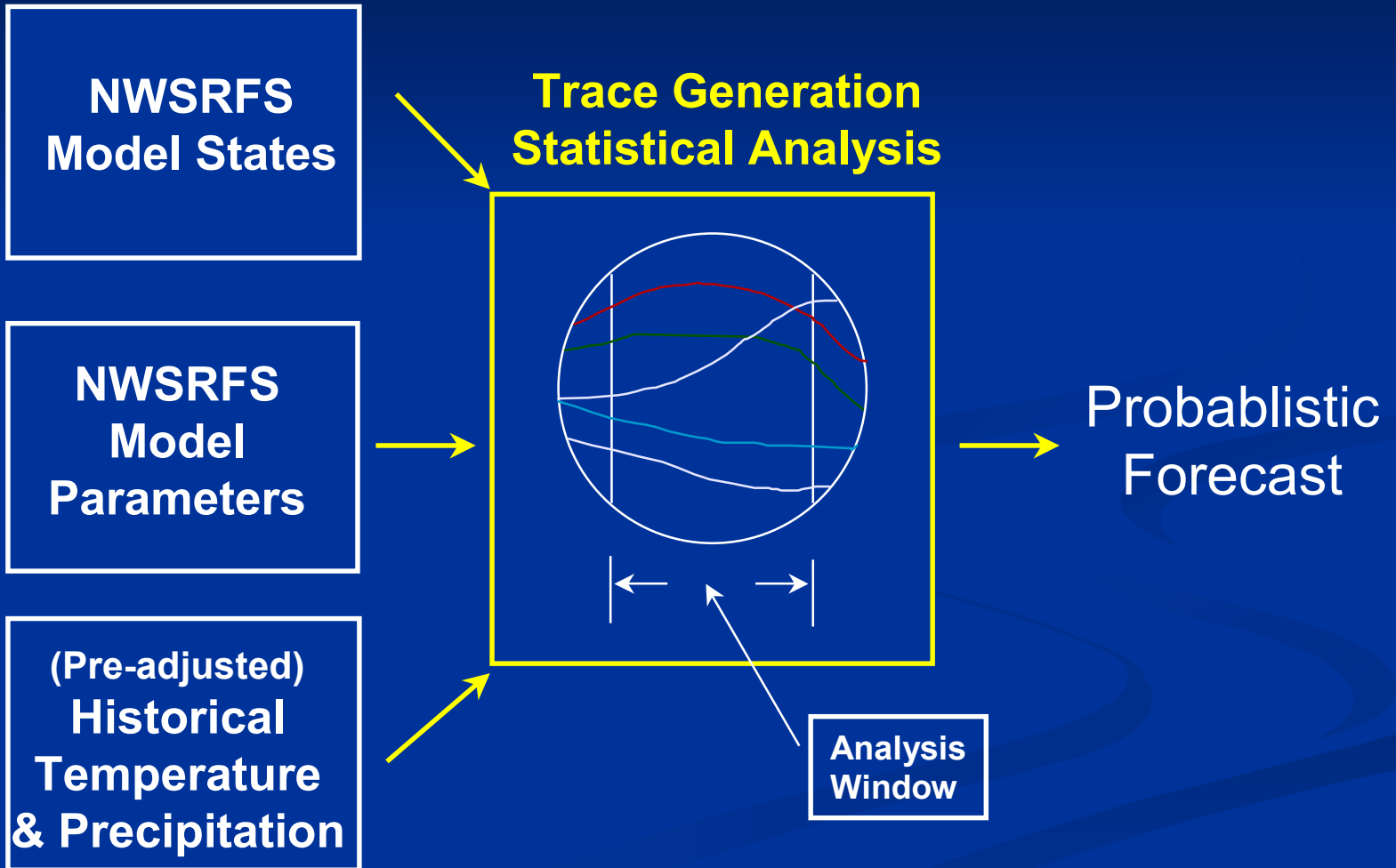


- More consistent with existing modeling system and operations.
- Effectively deals with temporal and spatial correlation.
  - Time and space relationships inherent in historical model inputs developed for calibration.
- Ability to incorporate and use short, medium, and long range weather and climate forecasts.





# ESP Process





# Use of Weather and Climate Forecasts



Historical  
MAT and MAP

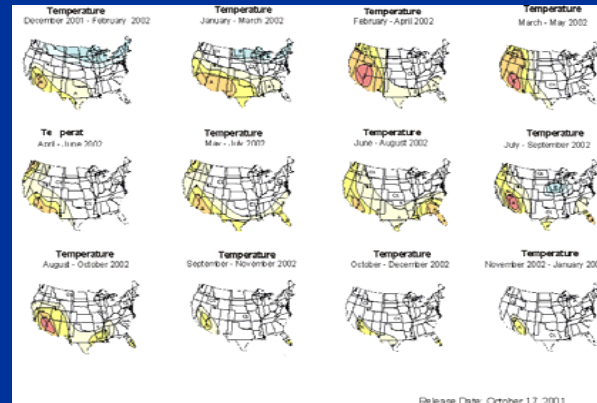
Adjustment  
System

Adjusted Historical  
MAP and MAT

## Weather Forecasts



## Climate Forecasts

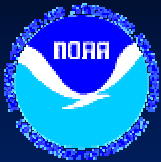




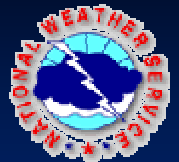
# Traditional ESP Applications



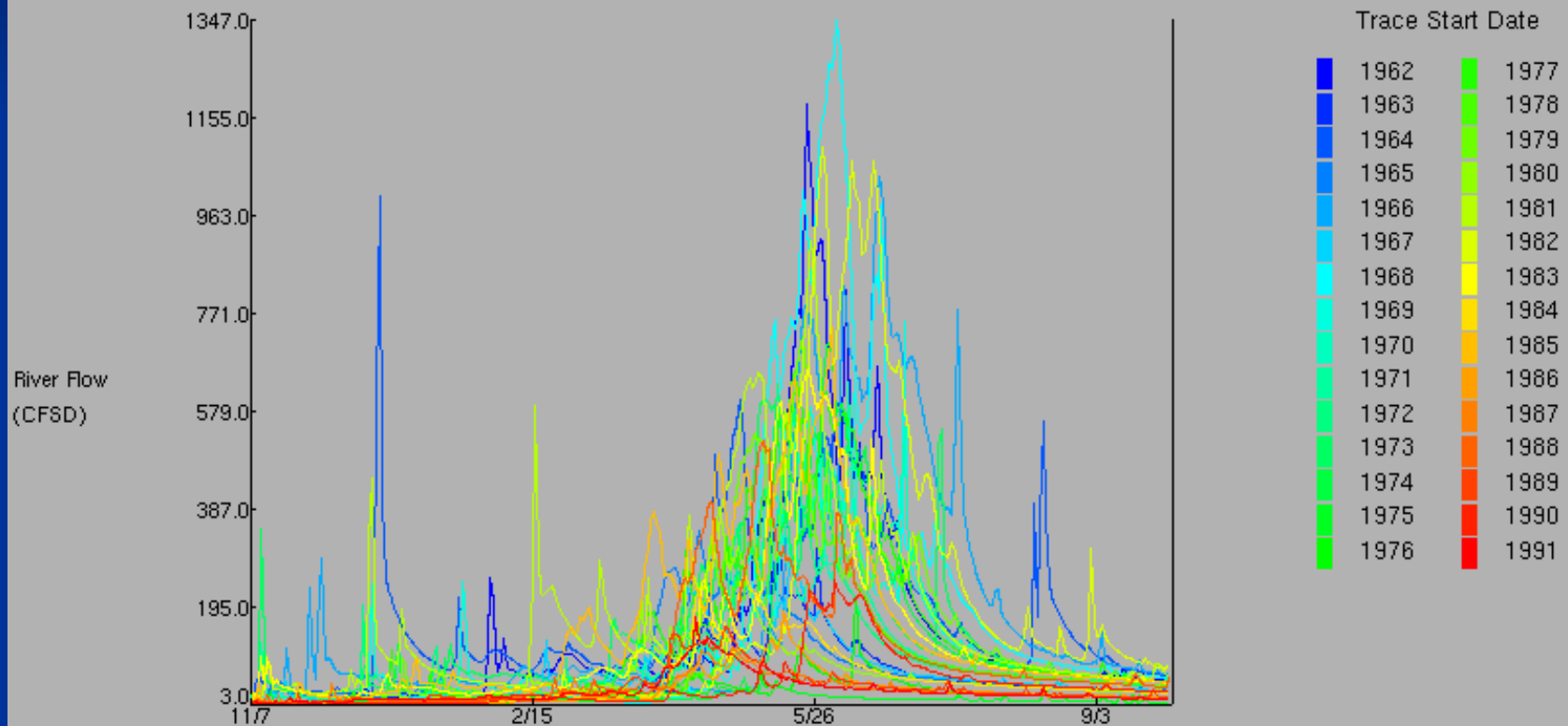
- Medium range snowmelt forecasts.
- Long range volume forecasts.
  - Complements traditional regression-based procedures.
- Peak flows, low flows, etc.



# ESP Trace Ensembles

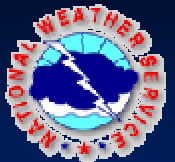


ESP Trace Ensemble of W F CARSON-WOODFORDS  
Latitude: 38.8 Longitude: 119.8  
Forecast for the period 11/7/2001 24h – 9/29/2002 24h  
This is a conditional simulation based on the current conditions as of 11/7/2001

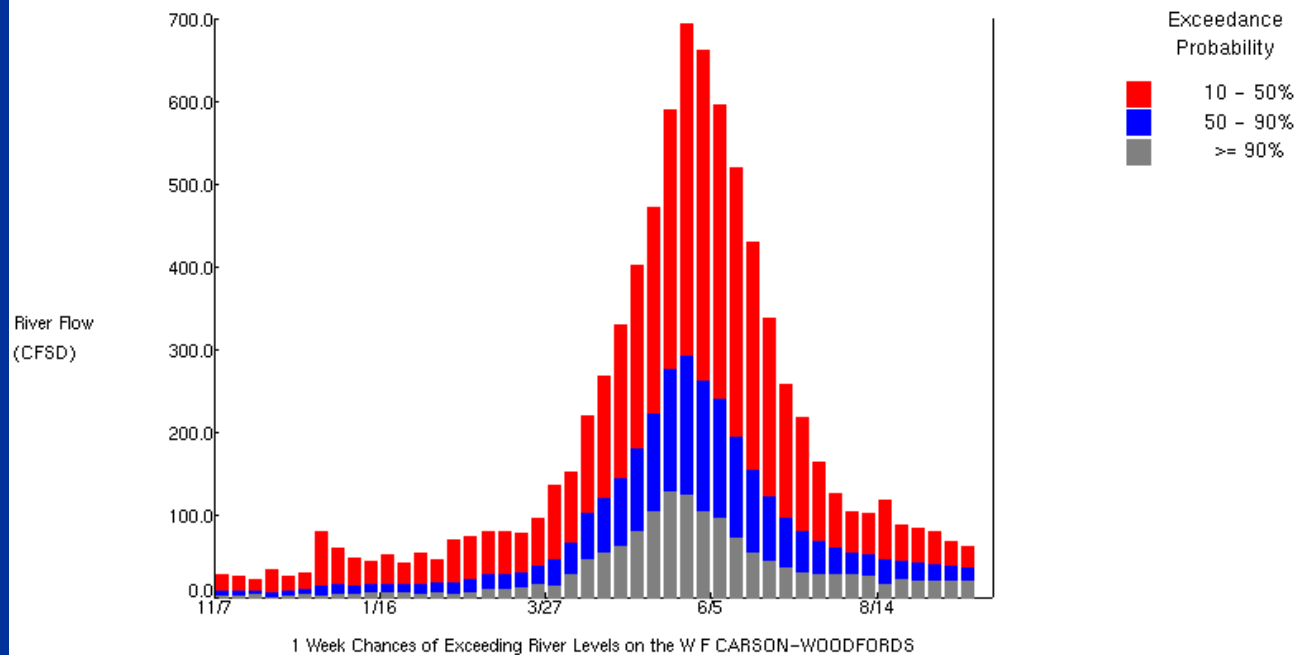




# Mean Weekly Flows



1 Week Chances of Exceeding River Levels on the W F CARSON-WOODFORDS  
Latitude: 38.8 Longitude: 119.8  
Forecast for the period 11/7/2001 - 9/25/2002  
This is a conditional simulation based on the current conditions as of 11/7/2001





**But we really need ensembles  
for the next 5 days at 6 hour  
intervals!**

**Useful for:**

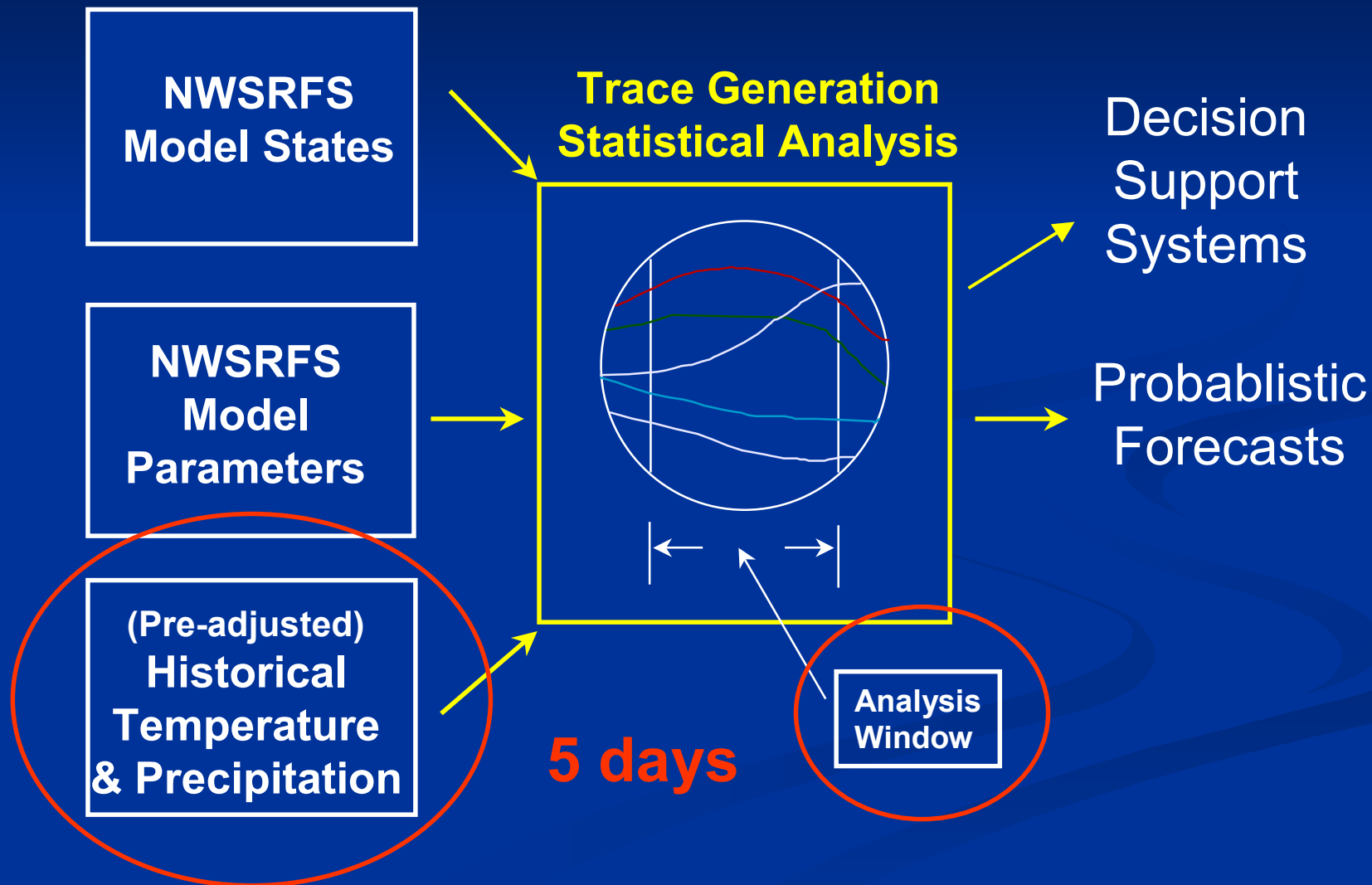
Hydrologic Forecasters

Emergency Services Community

Water Mangers (Reservoir/Flood Control Operations)



# Short-term ESP Process





# Short-term Ensemble Objectives



- Generate short-term weather inputs.
  - Precipitation (6 hourly)
  - Temperature (6 hourly)
- Preserve spatial and temporal relationships.
- Preserve skill in deterministic precipitation and temperature forecasts.





# Precipitation Calibration



- Observed Marginal Statistics (Climatology)
  - POP
  - Conditional mean
  - Conditional Cv
- Forecast Marginal Statistics (Climatology)
  - POP
  - Conditional mean
  - Conditional Cv
- Coefficient of correlation between transformed values of forecasts and observations



# Temperature Calibration



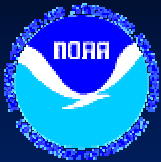
- Observed Marginal Statistics (Climatology)
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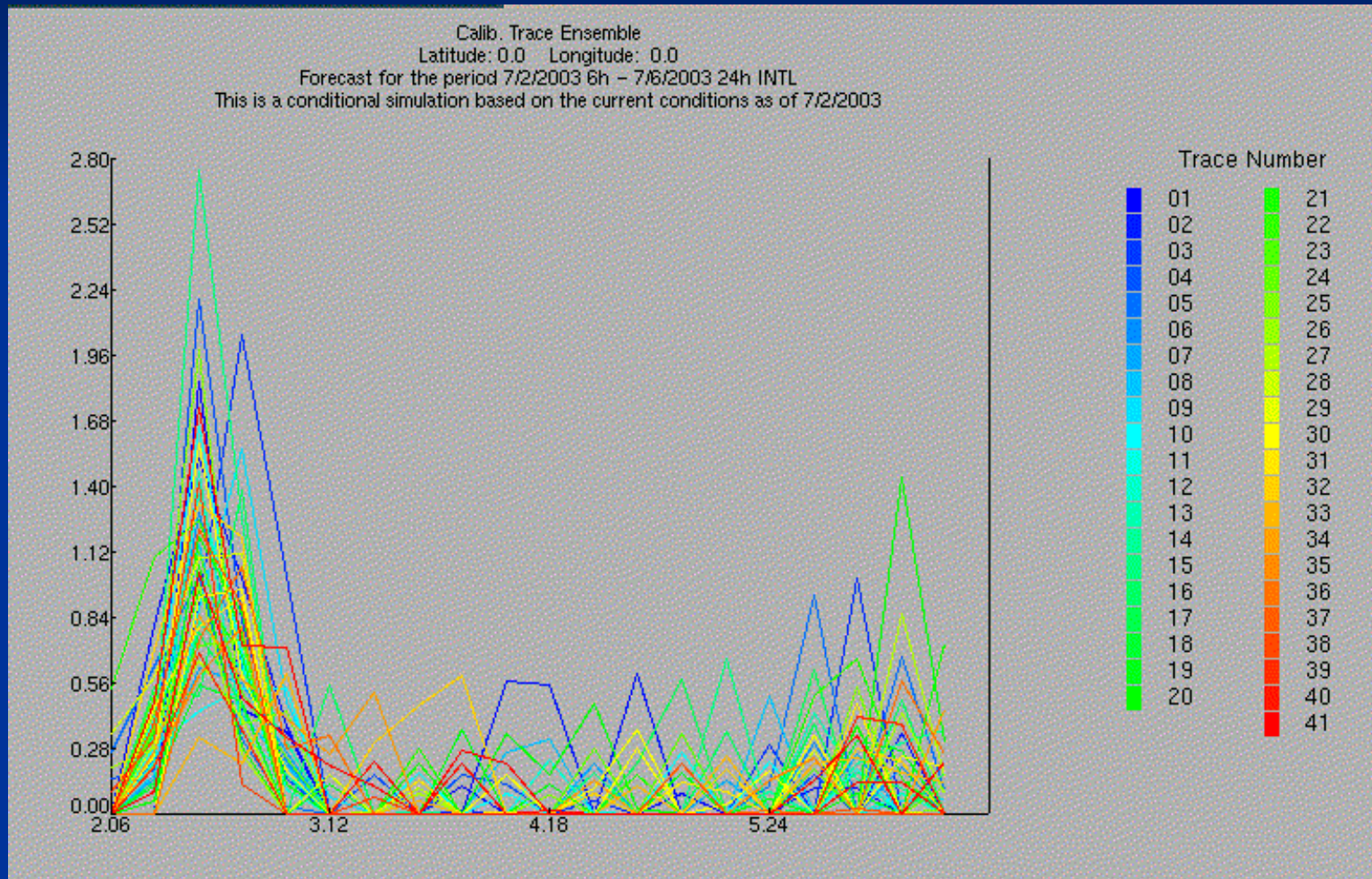
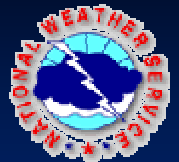
# Simple Explanation



- Historical time series are shifted within their observed distribution (climatology).
- The degree of shift is associated with the level of skill as exhibited in the forecast climatology.
- **Simple extreme examples:**
  - If there is NO SKILL in forecasting precipitation on day 5, then the precipitation ensembles will reflect pure climatology.
  - If there is PERFECT SKILL in forecasting precipitation on day 1, then the precipitation ensembles will all be equal to the deterministic forecast.



# 6 Hour Precipitation - Ensembles



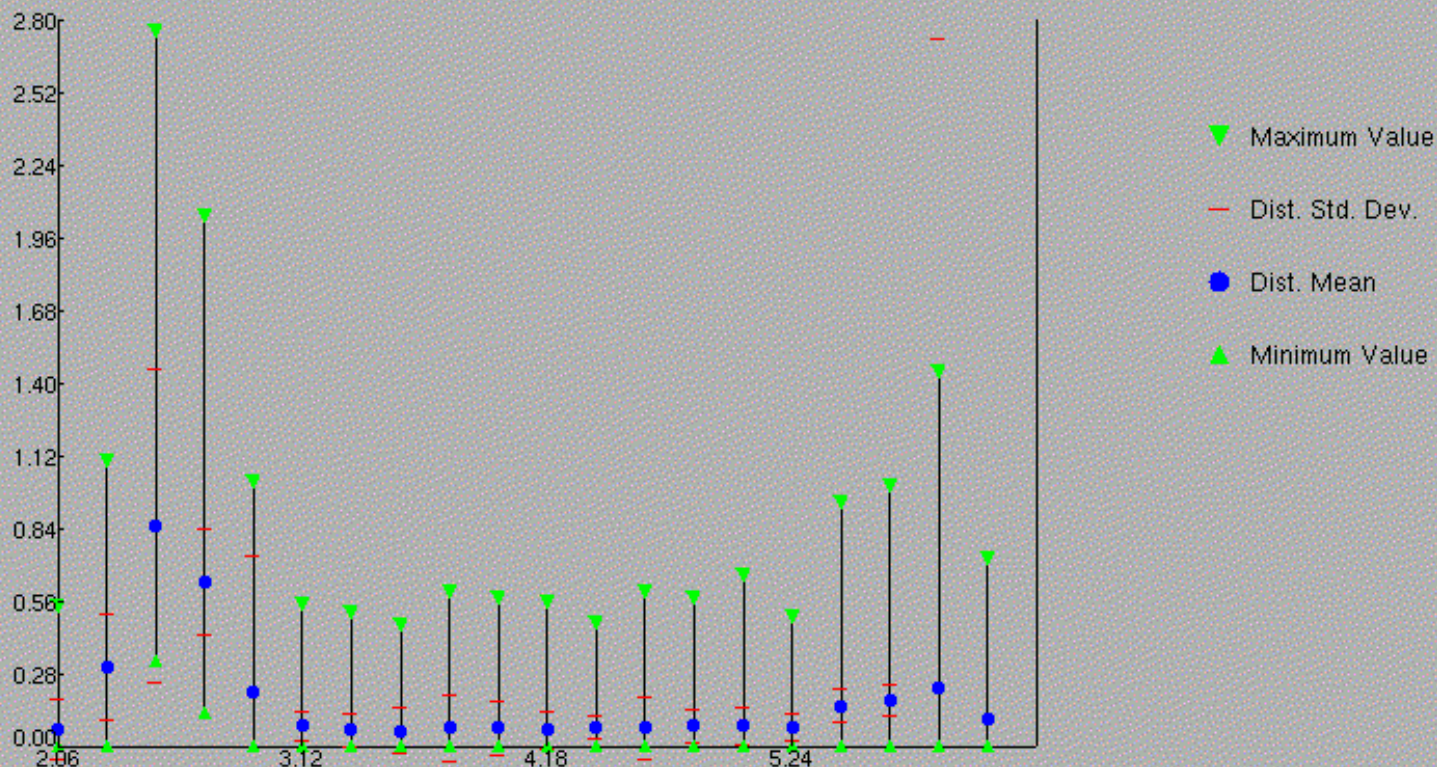




# 6 Hour Precipitation Expected Values



Calib. Expected Value  
Latitude: 0.0 Longitude: 0.0  
Forecast for the period 7/2/2003 6h - 7/6/2003 24h INTL  
This is a conditional simulation based on the current conditions as of 7/2/2003

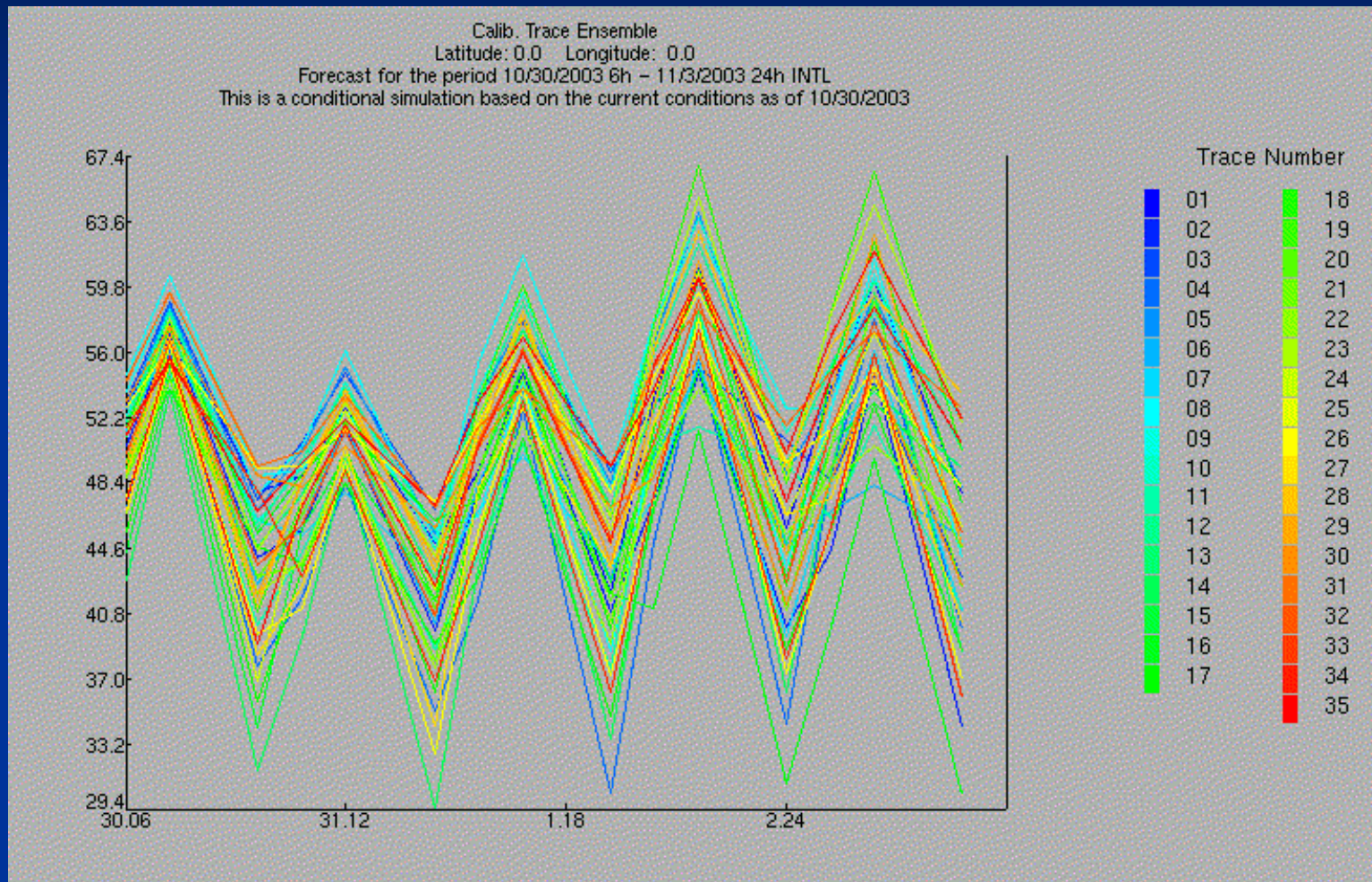
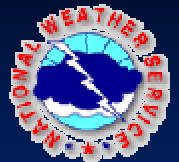


5.12, 2.30





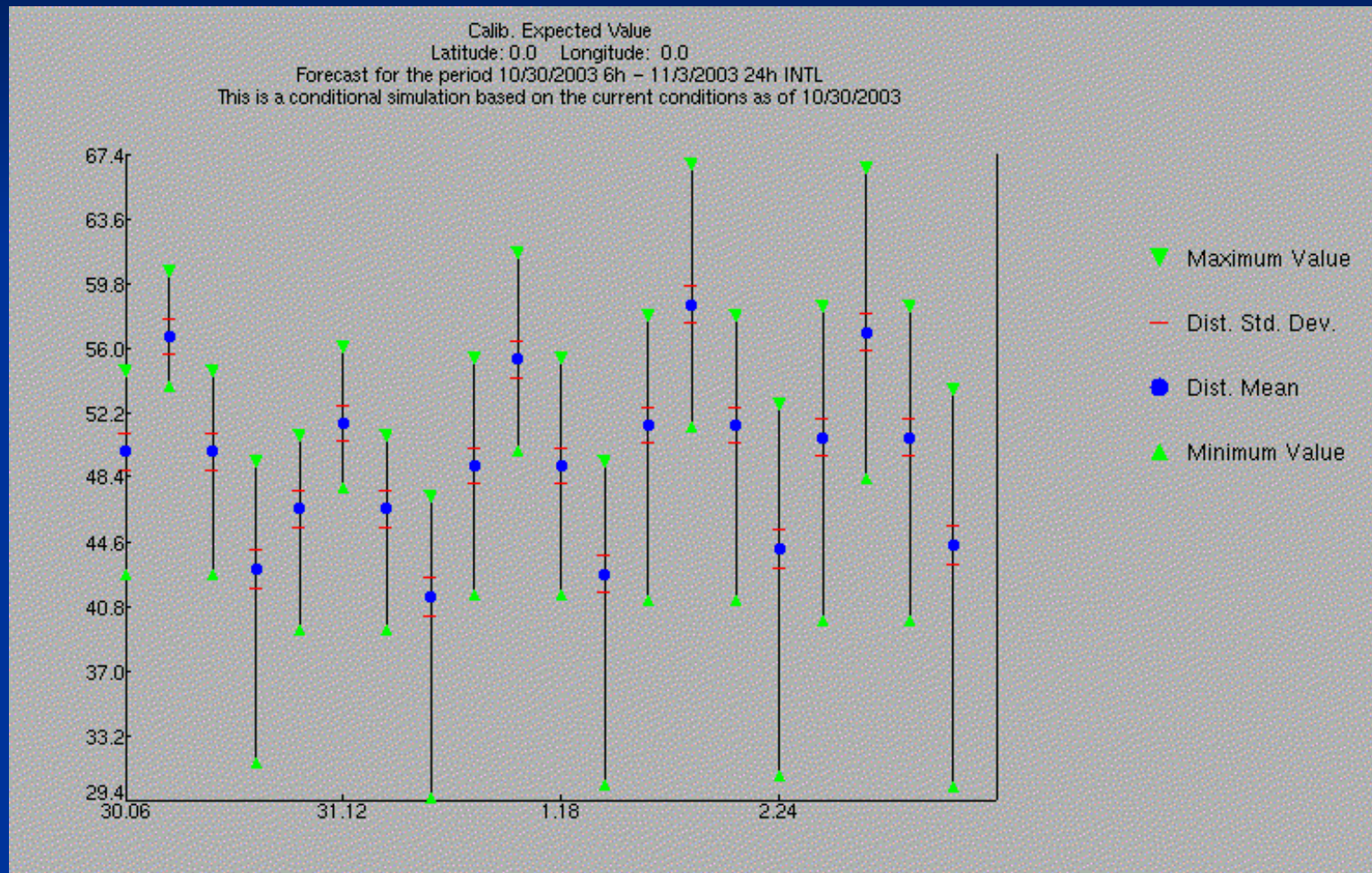
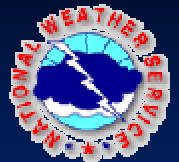
# 6 Hour Temperature - Ensembles







# 6 Hour Temperatures Expected Values





# Project Status



- Ready to begin generating and reviewing
  - Precipitation ensembles
  - Temperature ensembles
- Working on processing the inputs through the operational hydrologic models.
  - Within next month
- Prototyping operational environment
  - This winter





# Next Steps



- Integrate short-term ensembles with those shifted to reflect the medium and long range weather and climate forecasts. (hours to months)
- Re-engineer operational forecast system to take full advantage of the process.
- Collect data to validate forecast information and develop and provide meaningful reliability metrics.
- Assist customers/partners with appropriate interpretation and use of risk-based information.



# California-Nevada River Forecast Center



Thank You

